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TABLE OF CONTENTS

1. INTRODUCTION

During the past six-month reporting period, progress has been made on both fabrication of half-dipole antennas and on the testing of antennas with bismuth bolometers. The testing has been performed at 229 GHz with a Varian Extended Interaction Oscillator as the source. The testing, as discussed in the last semi-annual report, is being performed at three wavelengths, initially at 1.3 mm and then at shorter wavelengths, 119 μm and 10.6 μm. The operation at 10.6 μm will require photolithography techniques beyond our capabilities and will necessitate having work done outside the laboratory. The fabrication and testing techniques will have been established by the current activities.

With successful fabrication and testing of the antenna/bolometer arrays, attention is now being given to employing edge-MOM diodes as the sensing elements. These devices have characteristics that are required for power conversion. For shorter wavelengths, other antenna configurations such as the bow-tie will be fabricated for comparison with the half-dipole antenna.

In the sections that follow, work performed during the past reporting period is discussed. This includes fabrication and testing. Conclusions are presented and a brief description given of work to be performed during the next six-months.

2. WORK PERFORMED DURING CURRENT SIX-MONTHS OF PROGRAM

In this reporting period, successful fabrication of the bolometers has led to the observation of antenna action from the array elements. The antenna array consisted of a fused silica substrate, RF sputtered chrome/gold antennas and D.C. sputtered bismuth bolometers. An Extended Interaction Oscillator with output frequency of 229 GHz was used as the radiation source, and the half wavelength resonant dipole antenna elements were fabricated for this wavelength (1.3 mm in

air).

Approximately six antenna arrays with continuous refinements have been fabricated during this interim. Several significant observations have been made about the antenna design and fabrication process. Overall, the fabrication of the antenna arrays with bismuth bolometer has become standard technique, and work has started on the edge MOM-diodes discussed in a later section of this report.

A. Experimental

Early on, we found that increasing the flow but not the pressure of Argon through the DC Sputterer yielded a uniform, highly reflective bismuth layer repetatively. The increased flow also cut sputtering time from 2 hours to 40 minutes.

The following general experimental setup was used throughout this reporting period. The antenna/bolometer array is fabricated on a fused silica substrate (1.5" in diameter and 0.125" in thick). The substrate is mounted to printed circuit (PC) board using silicone rubber adhesive. The PC board is annular in shape and provides gold plated contacts so that the antennas can be connected to a biasing circuit. A K & S Ball Bonder with 1-mil gold wire is used to provide electrical conduction between the antenna and the gold contact. Common wire and solder can be used to complete the current biasing circuit. Finally, the PC board and substrate are placed in an intermediate mount which in turn is mounted to the Burleigh X-Z Inch Worm Translation Stage (see Figure 1).

The annular gold contact board is fabricated from 1 oz Kepro copper clad laminates. These are standard photosensitive copper covered PC boards. A rubylith mask of the sun burst pattern (see Figure 2) is placed on the board and then it is exposed to an ultraviolet source (e.g. carbon arc lamp) for 5.25 min. The board is then developed for 50 sec. in trichloroethylene and rinsed with deionized water. After this

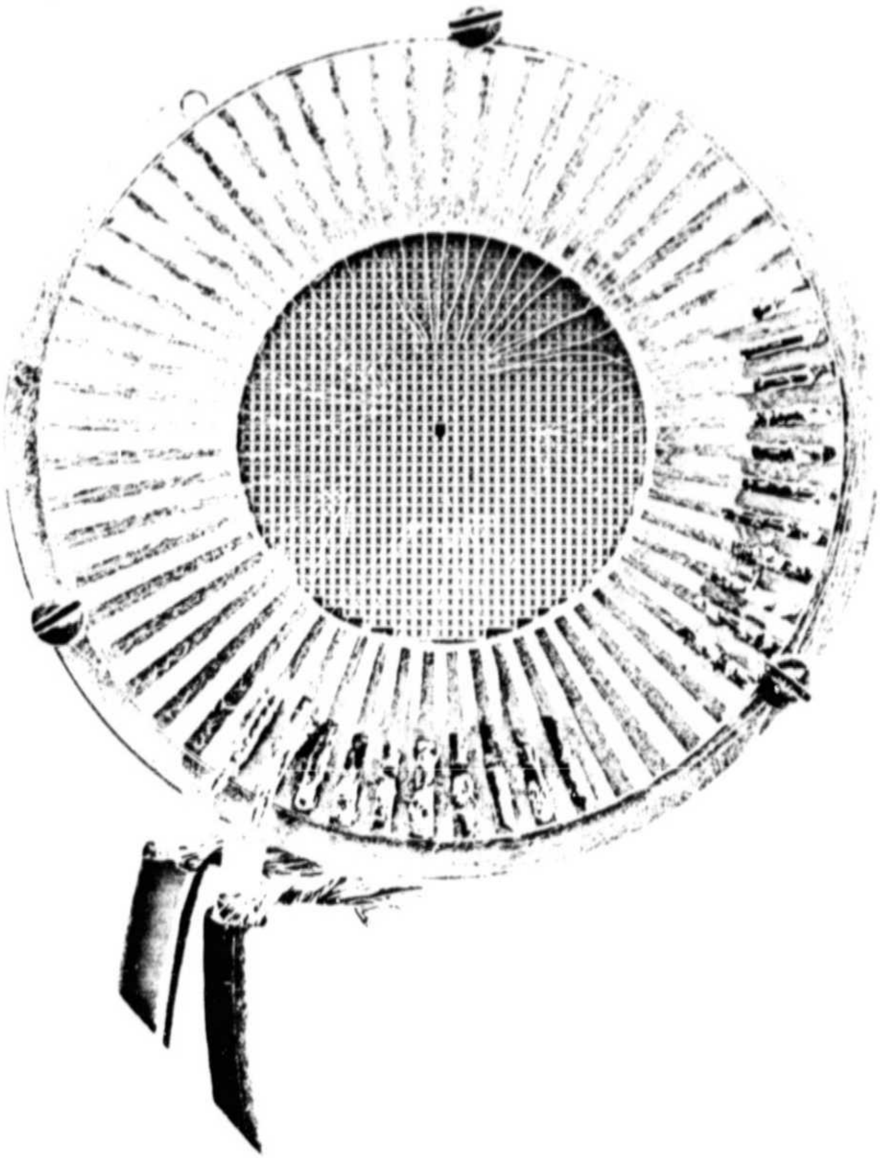

Figure 1. Photograph of antenna array mounting assembly and wiring.

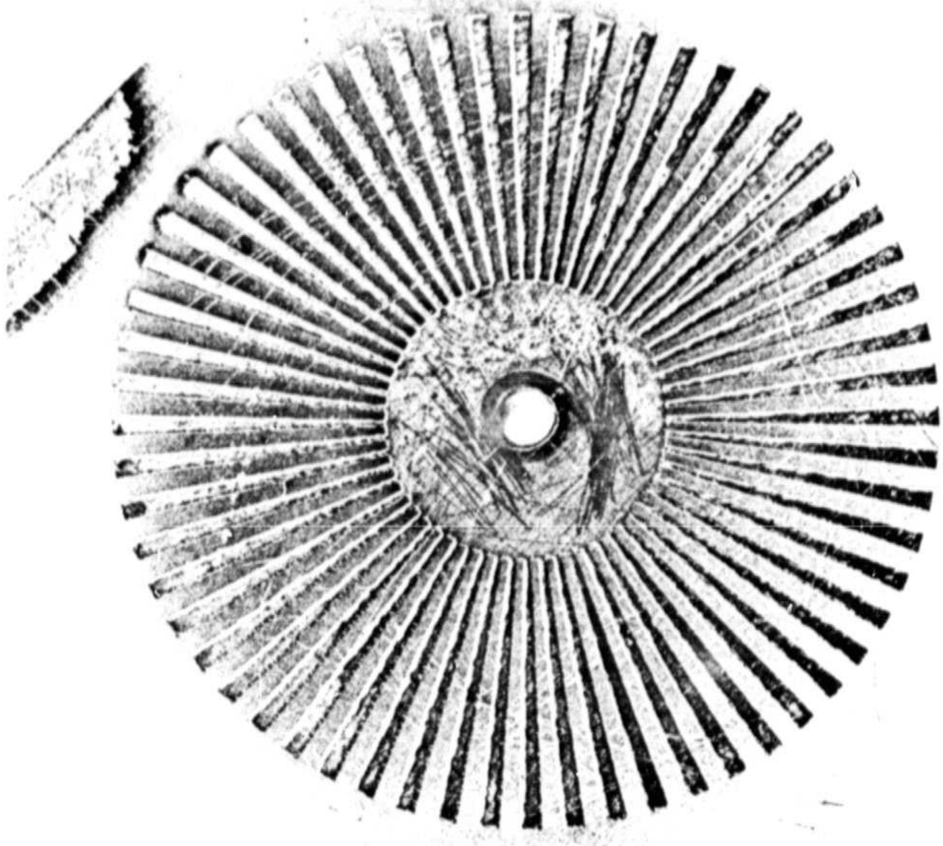

Figure 2. Photograph of gold plated sun burst pattern. This piece will be machined into the annulus form shown in Figure 1.

the board can be etched in a bath of $Na_2S_2O_8$ until the desired copper pattern is left. The last step is to plate successive layers of nickel then gold to the copper to insure good contact and adhesion with the gold wire in the ball bonder. Finally, the developed sun burst pattern (see Figure 2) is machined into an annular ring and is ready to be mounted to the silica substrate.

The current biasing circuit (see Figure 3) consists of an eight volt mercury battery, metal film resistors and 10-turn precision potentiometers. The circuit is designed to provide constant current, 5mA, to the bolometer enabling the detection of the change in resistance by the corresponding change in voltage across the bolometer. The complete current biasing circuit is enclosed in a metal box, and shielded coaxial leads to the antenna array are used to minimize the noise in the circuit. The potential on either side of the bolometer is fed into the transformer coupled, differential preamp of the lock in amplifier (PAR model 124 with model 116 preamp).

The radiation source used in this reporting period was a Varian Extended Interaction Oscillator model VKY2432M1. This tube generates radiation over a small tunable range centered at 229 GHz. The wavelength in air is 1.3mm.

During the testing of the first few antenna arrays the radiation was emitted directly from the waveguide (WR-8). However, this proved unsatisfactory since the far field pattern of a rectangular aperture is a two dimensional sinc pattern. This pattern is characterized by many local maxima in the radiation intensity which made it difficult to compare the antenna performance of several different antennas accurately . To correct this difficulty, a quasi-optical scheme was employed. A Gaussian profile horn was added to the end of the waveguide, and a Rexolite lens was inserted in the radiation path to collimate the beam. This correction proved to be satisfactory and the system was used in this form for the

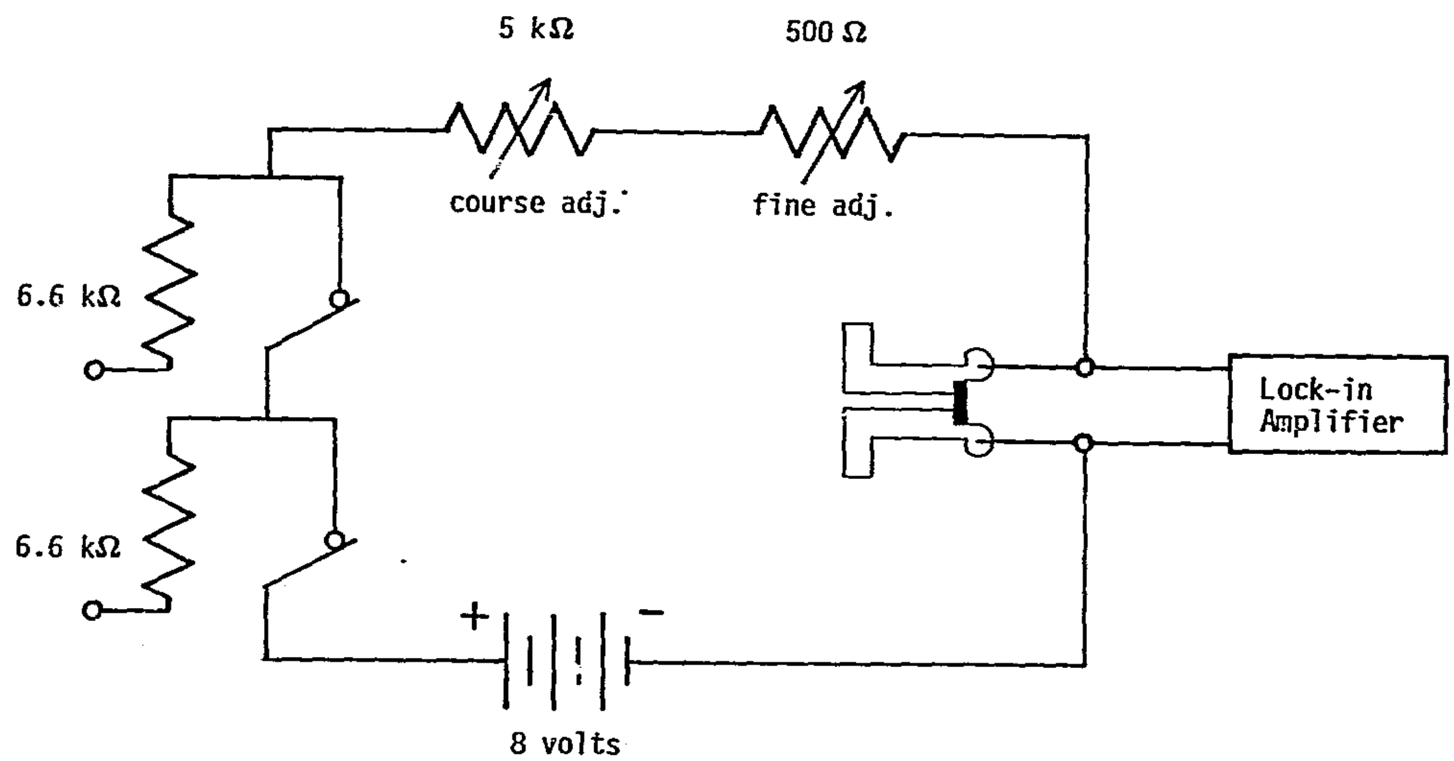

Figure 3. Schematic diagram of current biasing circuit. The two fixed 6.6 kΩ resistors can be switched in or out of the circuit depending upon the desire bias current and bolometer resistance.

remainder of the reporting period.

Pictured in Figures 4 - 6 is the complete experimental setup. The radiation is generated in the EIO and propagates in the waveguide to the bidirectional coupler. The coupler used in this setup directs a 20 dB sample of the radiation into a power meter in one direction and a frequency detection system on the opposite side. The majority of the power propagates out of the horn, through the lens and chopper and into the antenna array. The chopper is placed in the system to facilitate the use of a lock-in amplifier. Throughout the reporting period, the chopper was used at a frequency of 12.5 Hz to gain the large response from the antenna elements (Gallagher et al., 1984).

B. <u>Chronological Summary</u>

The original philosophy on how the bolometers are to detect the antenna performance has changed somewhat in this reporting period. The major consideration is how to discriminate between the heating of the bolometer due to antenna action and heating due to direct absorption of the radiation incident on the bismuth.

To distinguish between these two effects, several of the antenna arms of the array elements were removed with a razor blade. This set of antennas was then placed in the experimental setup described above and tested for antenna action. With the antenna arms removed, the array element consisted of the bolometer and bonding pads. Now a comparison of the antennas with bolometers and pads could be made with the bolometers and pads by themselves.

The results from this first measurement were encouraging. The average change in voltage (directly proportional to the change in resistance of the bolometers) was 3.11:1 for seven antennas with bolometers and pads versus six bolometers and pads alone. Also, preliminary measurements of the performance

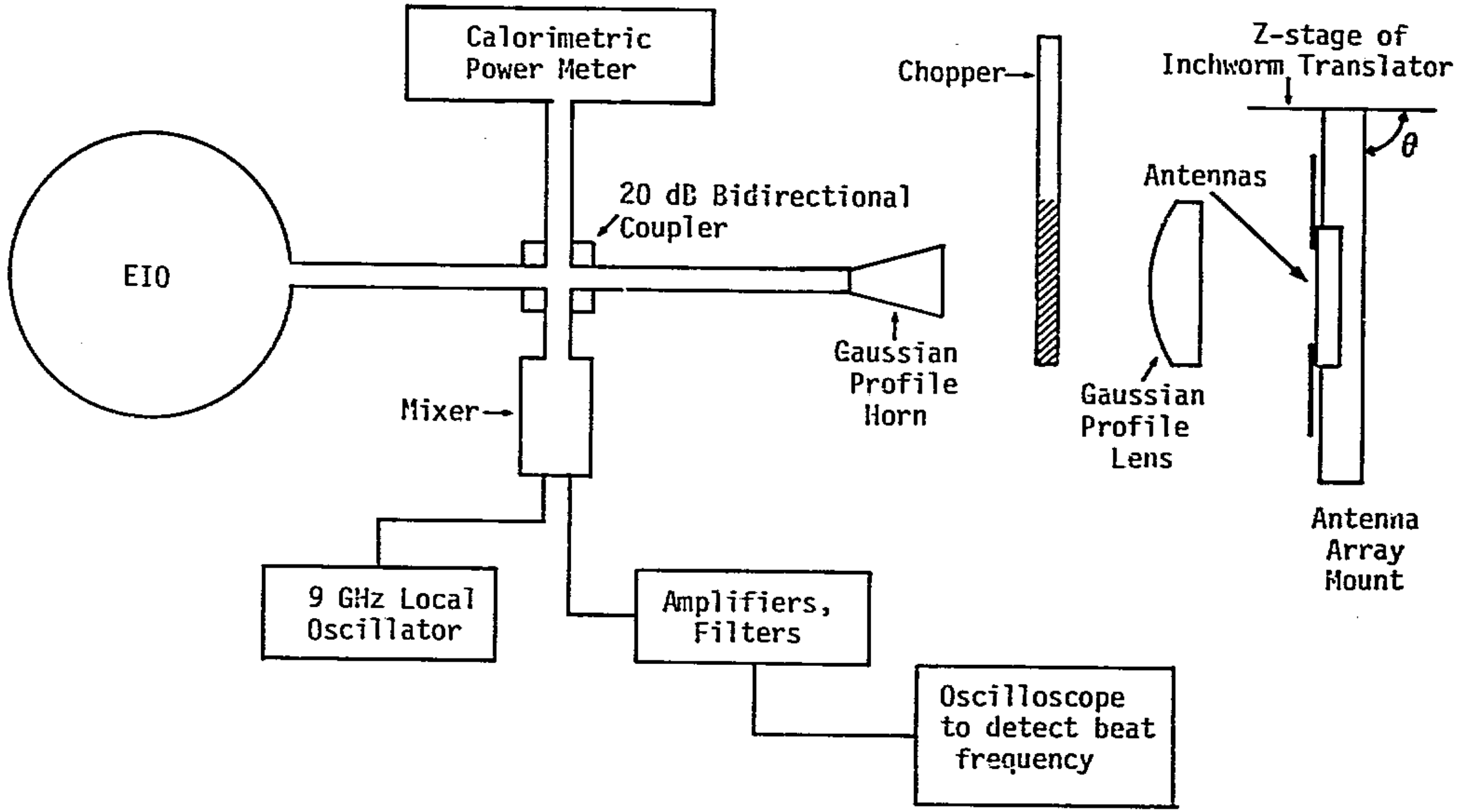

Figure 4. Schematic diagram of experimental set up.

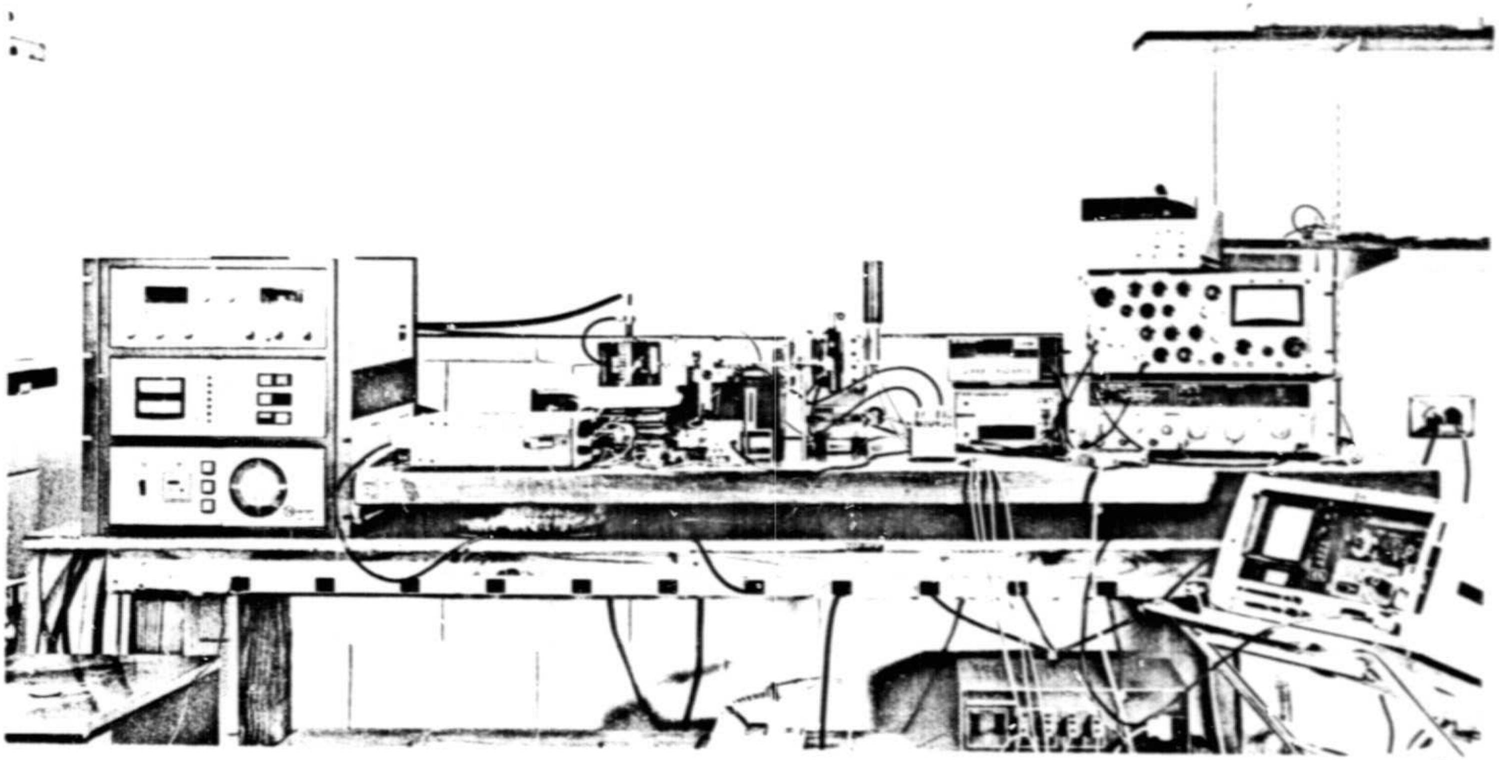

Figure 5. Photograph of entire experimental set up.

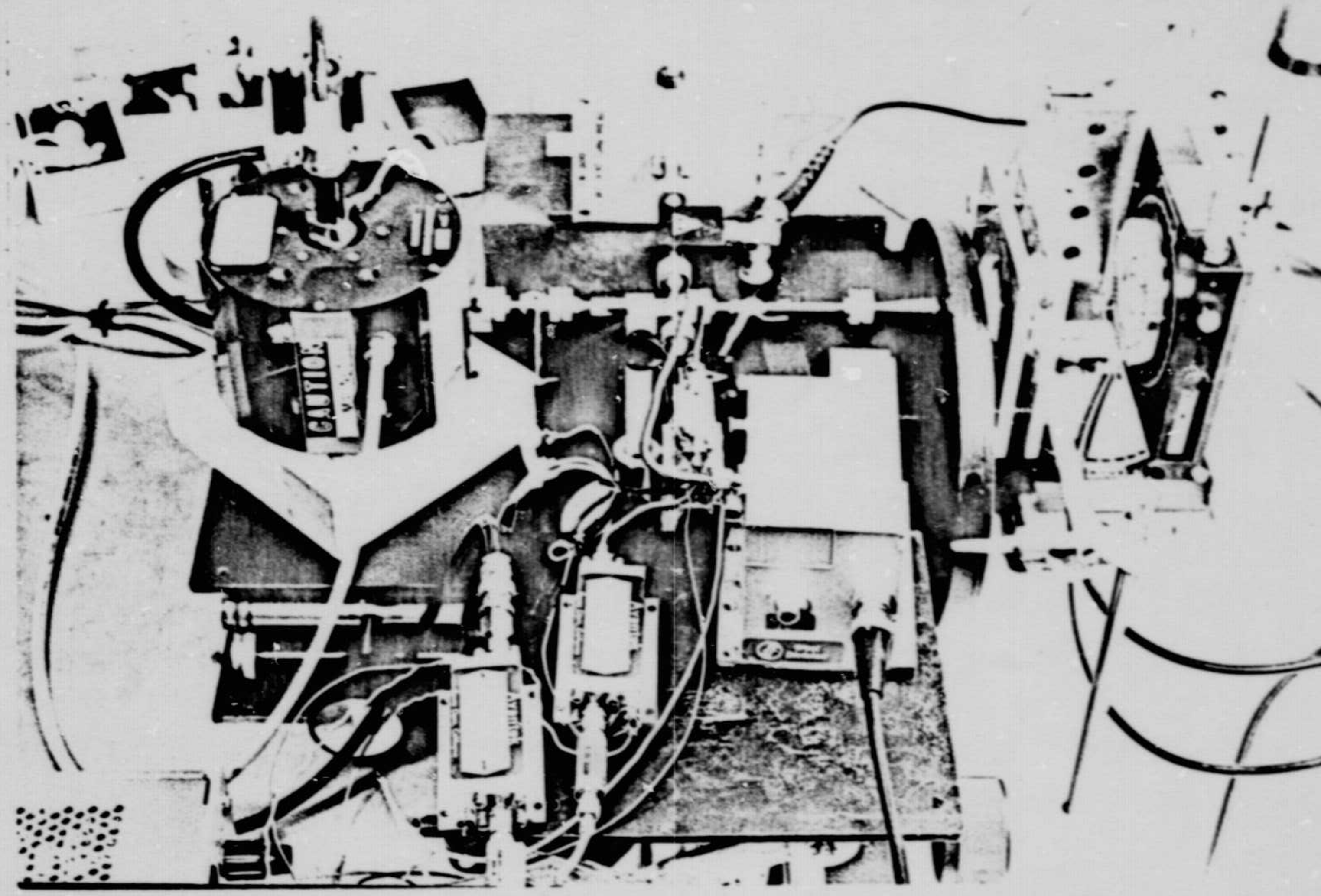

Figure 6. Close up photograph of the 229 GHz radiation generation, propagation and detection equipment.

of the antennas rotated 90 degrees with respect to the polarization of the incident radiation field were made. Here the measured change in voltage across the bolometers was 1.77:1 for the antennas correctly oriented with the polarized field versus the antennas rotated 90 degrees.

There were several shortcomings with this setup that were corrected for subsequent measurements. First, the maximum response of the bolometer element did not always occur at the same location in the radiation field, i.e., in comparing the performance of two different array elements, the maximum change in voltage across the bolometer in the second element was not found by simple translation to the location of the maximum response of the first array element. The rapid fluctuations in the intensity of the radiation emitted from the waveguide only aggravated this problem. (A rectangular aperture antenna produces a two dimensional sinc function radiation-field.) A more uniform Gaussian cross section field was obtained by using a quasi-optical system. A Gaussian profile horn antenna and Rexolite lens were added to the experimental set up.

A second shortcoming of this set of measurements was the amount of residue left by scraping the antenna arms off the substrate. Proper modifications in the fabrication phase were initiated to produce subsequent antenna arrays with several rows of bolometers and bonding pads only (see Figure 7). The next generation of measurements were performed on an optical bench for isolation from vibration. Securing all the apparatus to a common surface allowed for measurements more accurate and reproducible.

It should be noted that one array of antennas was ruined by bonding at too high a temperature. In this case temperatures in excess of 130^{o} centigrade were used with the result of changing the bolometer resistance from approximately 100 ohms to more than 10,000 ohms. It was felt although no investigation was made, that the contact between the gold and

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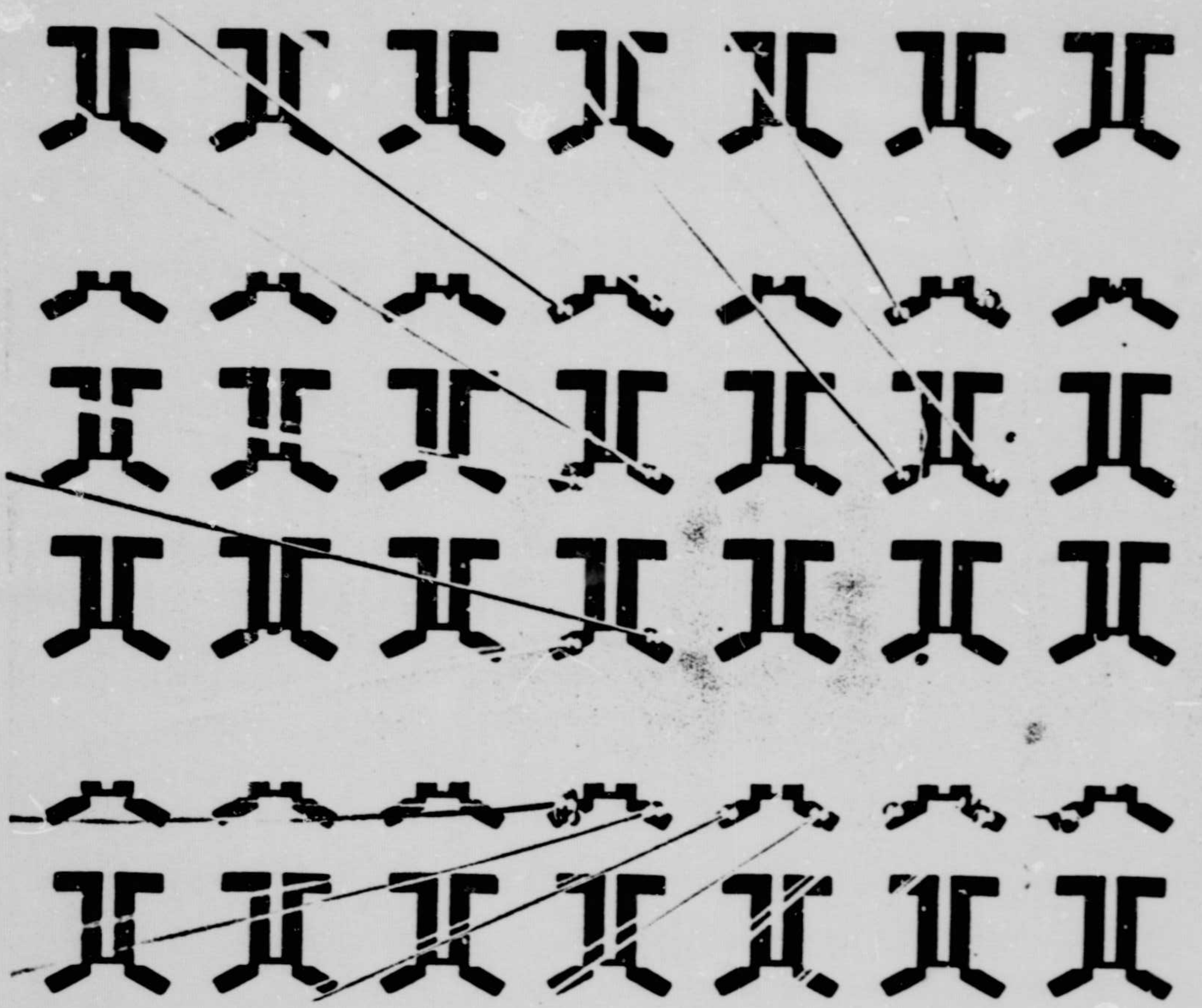


Figure 7. Photograph of array element with bolometer and bonding pads only.

bismuth deteriorated at these high tempertures. The most successful bondings on a Kulicke and Soffa model 4124 Universal Thermosonic Gold Ball Bonder have been made with the substrate at 81° centigrade and ball size at position 6. The bonding conditions were set at 2.38 and 3.73 for the search, 7.5 and 7.9 for the force, 3.3 and 4.5 for the time and 4.94 and 5.68 for the power. These settings are for the first bond on the antennas and the second bond on the gold plated sunburst respectively.

The next set of measurements were very successful and produced some significant results. The average measured change in potential across the bolometer for eleven antennas and for bolometer and pad elements was 345 μV and 208 μV respectively. The array was then rotated 90 degrees so that the half wave dipole antenna would not couple with the incoming radiation. An average of 27.6 μV for the antennas and 53.3 μV for the bolometers and pads alone were observed across the bolometer in this configuration. From these results it is felt that there are three contributions to the change in resistance of the bolometers: 1) direct heating due to the radiation incident on the bolometer, 2) antenna action from the antenna arms of the array element, and 3) antenna reaction from the bonding pads of the array element.

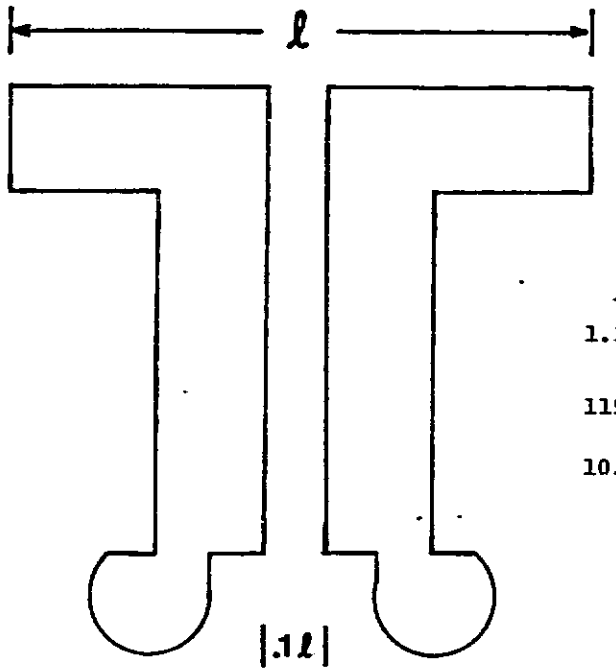
The original antenna configuration had been modified to its present form for two reasons (Gallagher et. al 1983). First, it was felt that the radiation would be focused to illuminate only the antenna arms so that the shape of the pads was not a critical factor in this early stage. Second, the larger pads would greatly reduce the difficulty of bonding the gold wire to the antenna. However, since the EIO that is used for the radiation souce is capable of producing two watts of power, it was not necessary to focus the incident beam on the antenna arms. Consequently, the present bonding pad configuration is producing some antenna action. To alleviate

this problem the next generation of antennas has been modified with smaller circular shaped bonding pads (see Figure 8). This modification should not present a major difficulty in the fabrication process because the expertise to bond to the smaller pads has been gained through experience with the ball bonder.

A preliminary antenna pattern for a single array element is shown in Figure 9. The coherence length of the EIO is approximately 50 meters so distinct maxima and minima in the voltage across the bolometer were observed as the X-Z translation stage was rotated. The plot in Figure 9 represents the maxima as a function of the rotation angle, θ. See Figure 4 for a schematic of the experimental set up. The 3 dB width of the main lobe is much narrower than what has been reported in the literature and will be investigated further in the next reporting period.

An initial investigation of the wavelength dependence has also been conducted, and the results are shown in Figure 10. The EIO is electronically tunable over a small bandwidth by adjusting the beam voltage in the tube. Plotted in the figure is the power output of the tube measured by a calorimeter on a 20 dB port of the bidirectional coupler and the change in potential across the bolometer versus the beam voltage and hence wavelength. Although no conclusion about the peak of the coupling as a function of wavelength can be made from this plot, it does show that the peak of the potential across the bolometer does not correspond to the peak of the power output of the tube; therefore, there is some antenna action taking place.

A new batch of antennas was bonded on this array in order to answer a few questions raised when testing the first batch. The most puzzling problem was that the position of adjacent antennas for maximum coupling did not correspond to a simple translation of the second an[illegible] to the former position of



λ	ν	air (ε = 1)	on SiO_2* (ε = 3.83)	in SiO_2	on GaAs* (ε = 12.5)	in GaAs
1.31 mm	229 GHz	655 (66)	537 (54)	334 (33)	364 (36)	184 (18)
119 μm	2.52 THz	58.5 (5.9)	~~5~~48.0 (4.8)	30.4 (3.0)	32.6 (3.3)	16.5 (1.7)
10.6 μm	28.3 THz	5.3 (.5)	4.3 (.4)	2.7 (.3)	3.0 (.3)	1.5 (.15)

*reduction factor for antennas on substrate extrapolated from K. Mizuno, Y. Daiku and S. Ono, IEEE Trans. Microwave Theory Tech., MTT-25, 470 (1977).

Figure 8. New antenna configuration w/round pads.

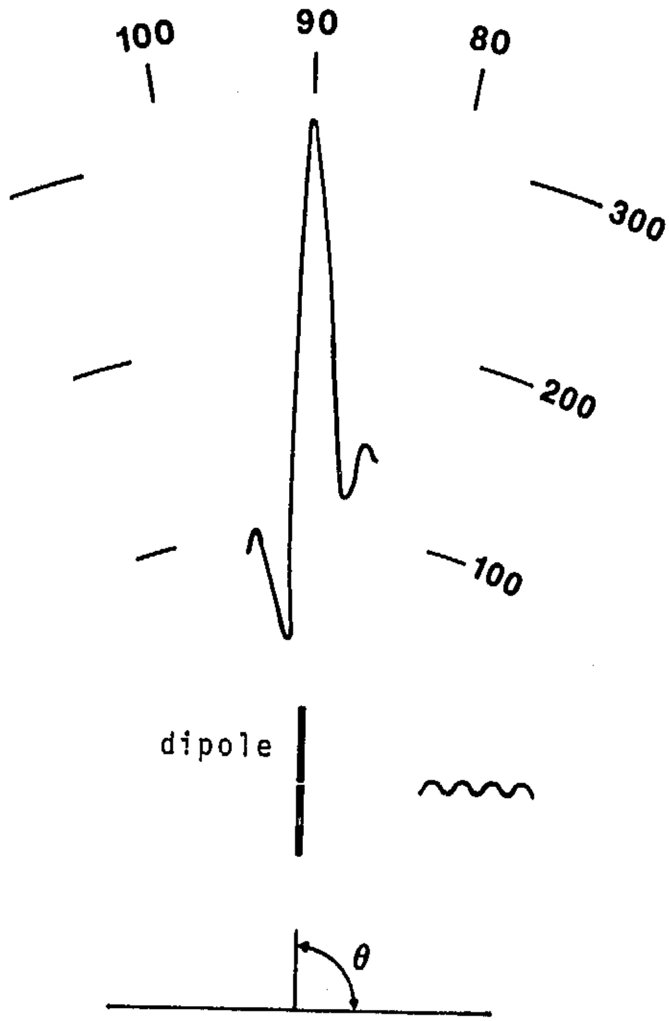


Figure 9. Plot of antenna pattern.

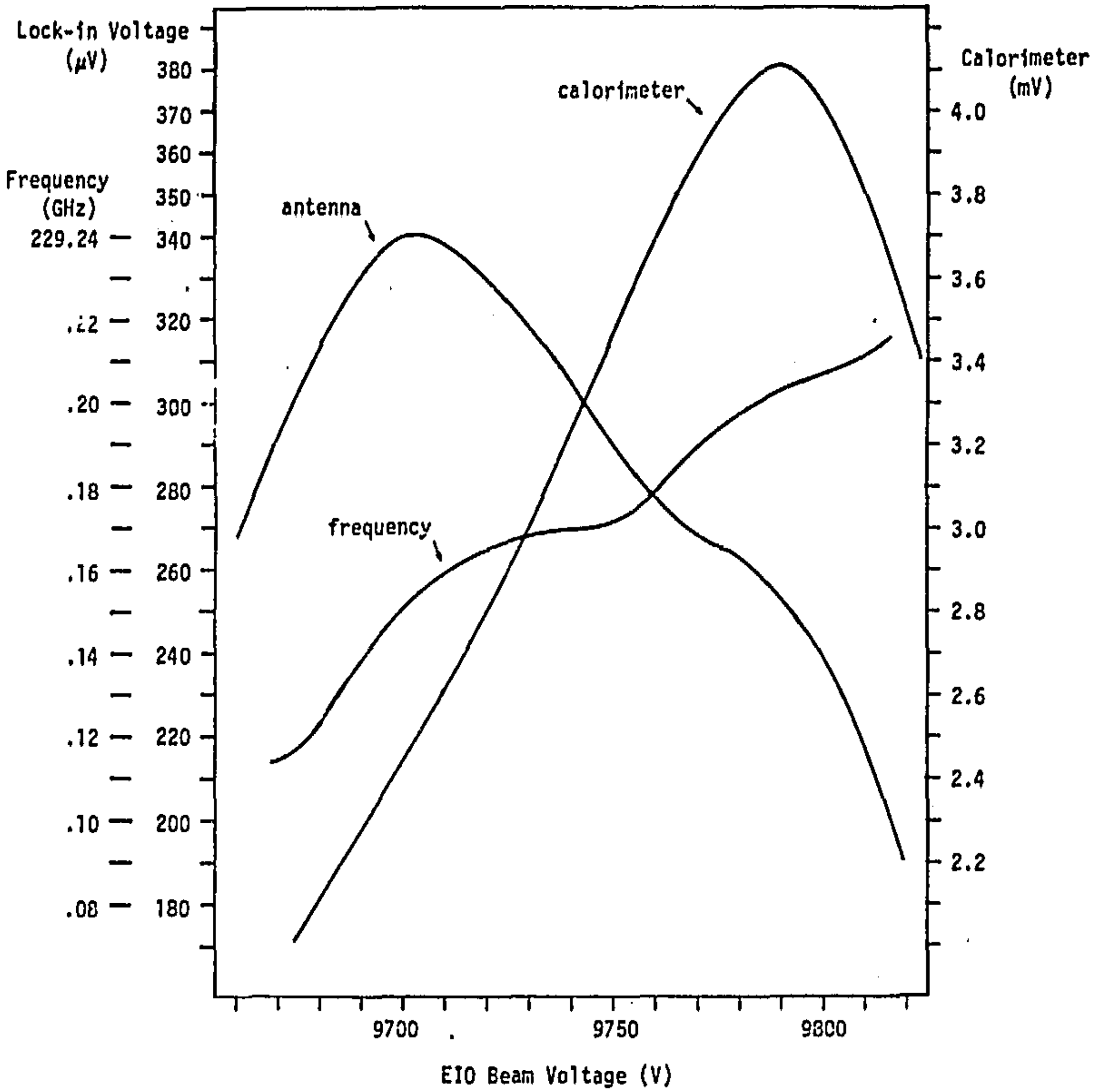


Figure 10. Lock-in, power meter vs. frequency

the first antenna. After careful examination of the antennas it was found that many of the gold leads physically crossed over the antenna arms of the array elements. Seven adjacent antennas were bonded with the gold leads clear of the antenna arms to test if this was the problem. Indeed this did turn out to be the cause of the discrepancy.

The last investigation that was carried out in the reporting period was to see how the antennas behave when connected in series and parallel. Two sets of four antennas were connected in series (see Figure 11) and two sets in parallel (see Figure 12) and tested for response under the incident radiation. All four sets were biased with five mA just like the other antennas. Surprisingly, the antennas in series did not show a response significantly different from a single antenna element. However, the parallel configurations showed a two-fold increase in response over a single element.

This result seems counter intuitive if the problem is approached from the circuit analysis point of view. The detection system is designed to measure (indirectly) the change in resistance caused by heating the bolometer. The series configuration should have produced a four fold change in resistance and an increase by a factor of four in the response, but this was not observed. On the other hand, the parallel configuration should have decreased the effective change in resistance by a factor of four. This would lead to a decrease in the reponse, however, an increase was observed. No further investigations have been made into this finding.

3. SUMMARY OF FINDINGS

Fabrication of the best antennas arrays was made more facile with finding that:

- Increased Argon flow during the DC sputtering produced more uniform bismuth films
- bonding to antennas must be done with the substrate

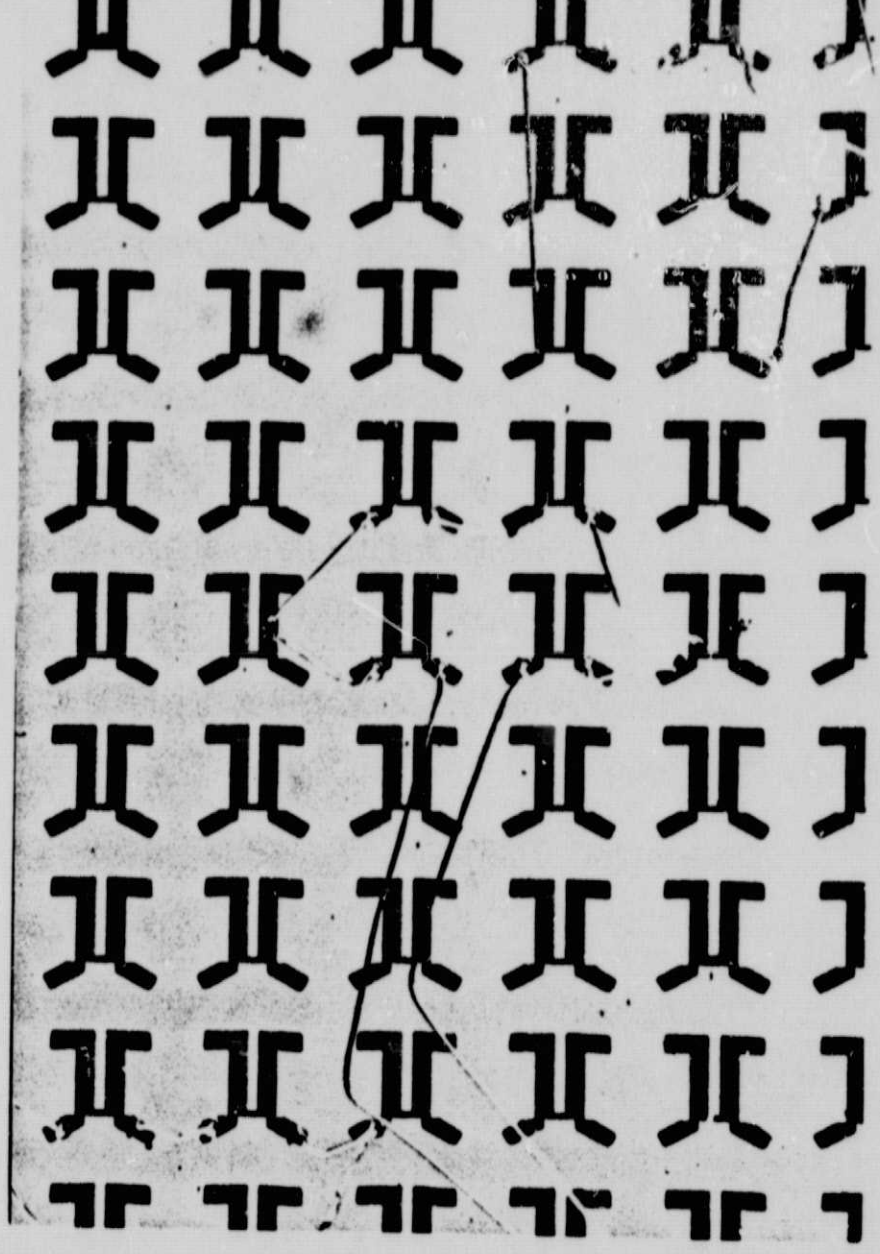


Figure 11. Photograph of series wiring of two sets of four antennas.

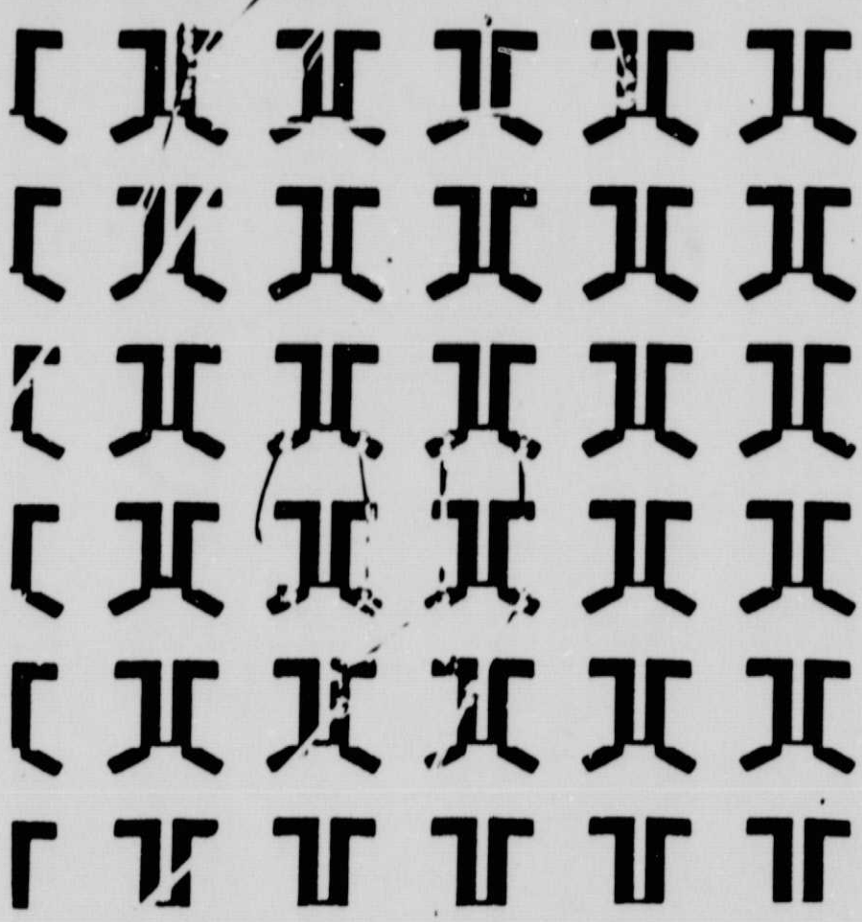


Figure 12. Photograph of parallel wiring of two sets of four antennas.

temperature below 100°C. Higher temperatures damaged the bolometers. During the testing of the antennas, it was found that the use of a quasi optical system provided a uniform radiation field.

The plot of output power of the EIO, response of antenna vs. beam voltage shows that antenna action is taking place. Bolometer response differences between antenna aligned and perpendicular to the E-field affirms this antenna action. However, the bonding pads appear to be coupling to the radiation. Also bonding wires interfered with antenna action. When the bonding wires were not crossing in front of the antenna arms the response was more consistent. The pads will need changing.

Groups of antennas were bonded in series and in parallel with the parallel configuration showing the greater response.

4. DIRECTIONS

From the information gained in the last six months, the program will take the following direction:

1) Round bonding pads will be tested to see if such an arrangement lessens the coupling of the bonding pads to the electromagnetic radiation (i.e. isolating the antenna's action).

2) Comparison of coupling efficiencies will be made with the antenna looking directly at the radiation and with the antenna looking through the substrate at the radiation.

3) Metal-oxide-metal (MOM) diodes will be fabricated into the antenna array. The diodes will take the form of the Edge-MOMs, which provide small area configurations and have been discussed in the most recent Interim Report. The Edge-MOMs integrated into the dipole antenna is illustrated in Figure 13. Photomasks have been made for building an Edge-MOM/antenna for 229 GHz. The Edge-MOMs are known to be sensitive to static electricity (Heiblum et al,). To lessen this problem, the

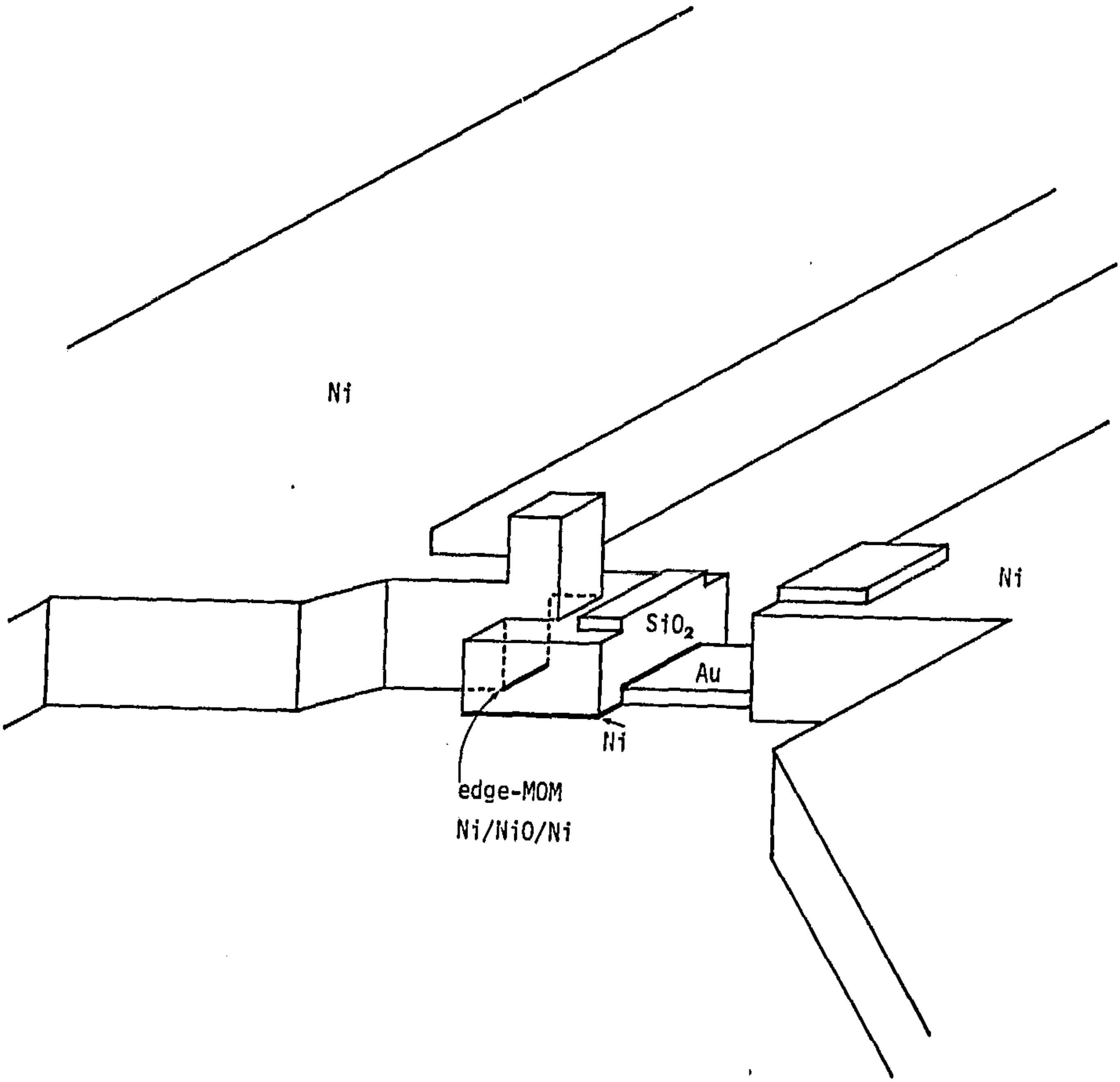


Figure 13. Configuration of Edge-MOM Incorporated in Dipole Antenna.

will be reassembled in a constant humidity box (60% using $NaBr \cdot 2H_2O$).

4) Techniques for quantitative determination of power conversion will need to be developed. In order to determine the power conversion efficiency of the elements of the rectenna arrays, precise values of power density falling upon the antenna will have to be evaluated. This investigation will be performed at 1.31 mm.

REFERENCES

1. J. J. Gallagher, C. J. Summers and D. P. Campbell, "Infrared Technology for Satellite Power Conversion," NASA Research Grant No. NAG3-282, First Semi-Annual Report, January, 1983
2. J. J. Gallagher, D. P. Campbell and M. A. Gouker, "Infrared Technology for Satellite Power Conversion," NASA Research Grant No. NAG3-282, Third Semi-Annual Report, February, 1984
3. M. Heiblum, S. Y. Wang, J. R. Whinnery, and T. K. Gustafson, "Characteristics of Integrated MOM Junctions at DC and at Optical Frequencies," IEEE Journ. Quantum Electron., QE-14, 159 (1978)